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Laser Micromachining of THz Components

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Abstract **– Laser micromachining techniques can be used to fabricate high-quality waveguide and quasi-optical components to micrometer accuracies. Successful GHz waveguide designs can be directly scaled to THz frequencies. We expect this promising technology to allow the construction of the first fully integrated THz heterodyne imaging arrays. At the University of Arizona, construction of the first laser micromachining system designed for THz waveguide components fabrication has been completed. Once we have tested and characterized our system we will use it to construct prototype THz 1x4 focal plane mixer arrays, AR coated silicon lenses, THz LO sources, phase gratings and more. The system can micromachine structures down to a few microns accuracy and up to 6 inches across in a short time. This paper discusses the design and performance of our laser micromachining system, and illustrates the type and range of components this exciting new technology will make accessible to the THz community.**

INTRODUCTION

Laser processing offers many advantages over conventional machining of micrometer sized components [1]. Thanks to the ability to finely focus laser light, smaller features can be achieved with improved tolerances. Because chemically activated laser etching is a non contact process, there is no mechanically induced material damage, no hard to remove particulate residues, and no tool wear or machine vibration. Laser fabrication therefore yields finer finishes, improved accuracy, and lower process overheads. The chemical activation on which this process is based minimizes the etching energy requirement and therefore reduces the potential for cracking [1].

LASER MICROMACHINING PRINCIPLES

An Argon-Ion laser is used to heat a microscopic portion of the silicon substrate in a chlorine ambient. At the onset of melting, volatile silicon chlorides are formed. The highly non-linear activation energy of the process confines etching to a molten zone only a few microns across. Crystalline materials have the benefit that un-etched portions of the molten zone grow back epitaxially, allowing controlled shavings to be removed plane by plane. Structures can thus be built by limiting the etch depth at each scan plane, to typically 1 μm, (see Fig. 1).

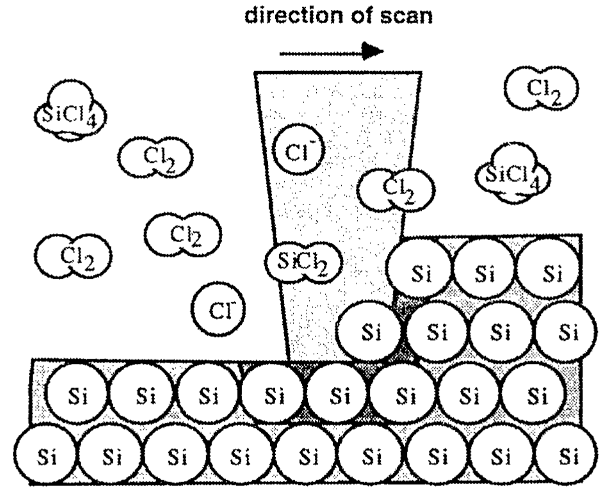

Fig. 1: Schematic representation of laser etching of silicon in chlorine ambient. Using high numerical aperture (NA) optics the reaction can be confined to a region only a few micrometer in size. The obvious trade off of high NA is a tapering of the beam that can be significant for some applications eg. Vertical walls [1].

At Steward Observatory we have built a laser micromachining system that follows the successful Lincoln Laboratory design and is optimized for THz applications.

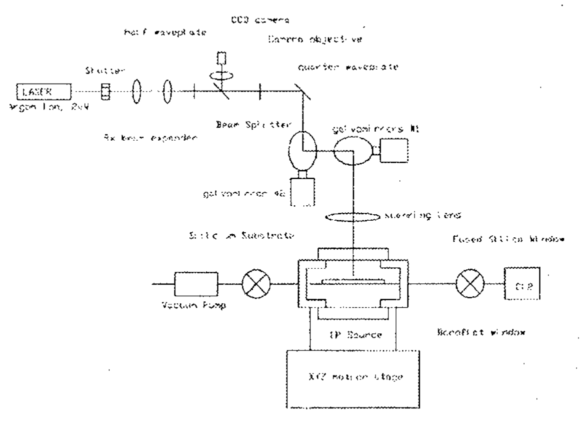

Fig. 2: Schematic of Steward Observatory's laser micromachining system

In our design the 18W Argon-Ion laser beam is expanded to 16mm, then deflected, using a commercial X-Y galvomirror scanner, onto achromatic scanning lens. The focused beam is then introduced through a fused silica window into a stainless steel reaction chamber containing the sample (see fig. 2).

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The wafer surface is typically biased to 100°C using an IR illumination source shining through a second window on the back side of the reaction chamber (see Fig 3).

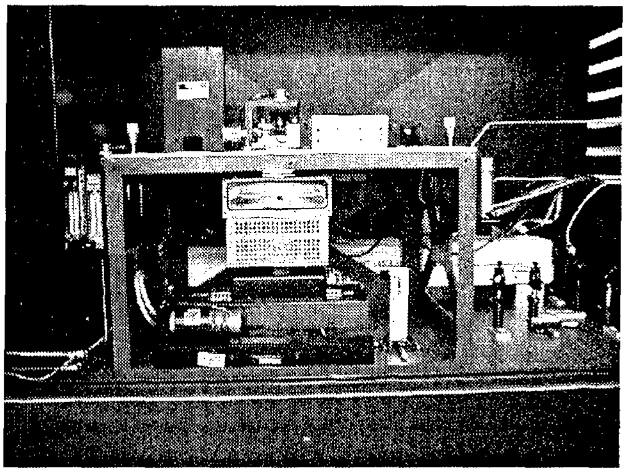

Fig. 3: Detailed view of the galvomirror scanner, reaction chamber, IR heater and X-Y-Z motion stages

The process is monitored through the focusing optics using a CCD with a plate scale of 7 μm per pixel. The scanning system is driven directly from computer generated patterns which can be constructed using Autodesk's AutoCAD. The ensemble is mounted on computer controlled X-Y-Z precision motion stages (see Fig. 3) allowing the stitching of large structures.

Before operation the cell is evacuated, then filled with 99.9 % pure chlorine gas to 100 Torr. After 2 hours of machining the remaining chlorine gas and silicon chlorides are vented through a scrubbing bubbler before release in the atmosphere. Figure 4 shows the system in our laboratory. The chlorine and nitrogen gas cylinders are stored in the gas cabinet on the right. The central hood houses the laser, reaction chamber, and optics. The vacuum pump and chlorine scrubbers are contained in the small gas cabinet on the left.

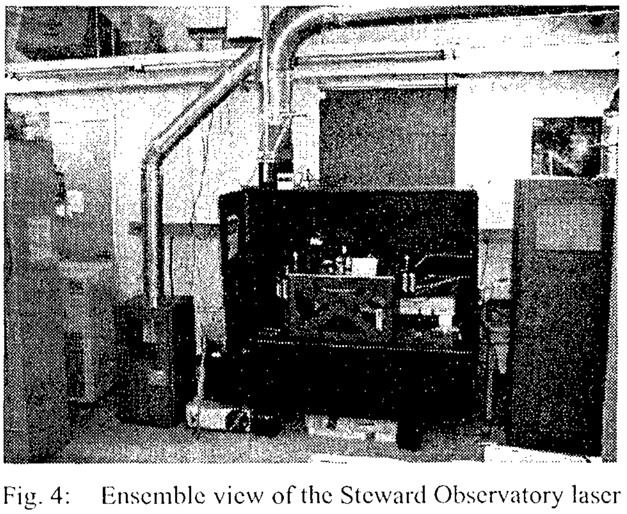

Fig. 4: Ensemble view of the Steward Observatory laser micromachining system

Figure 5 shows the electronic shutter and beam expander portion of the optical system with the laser turned on.

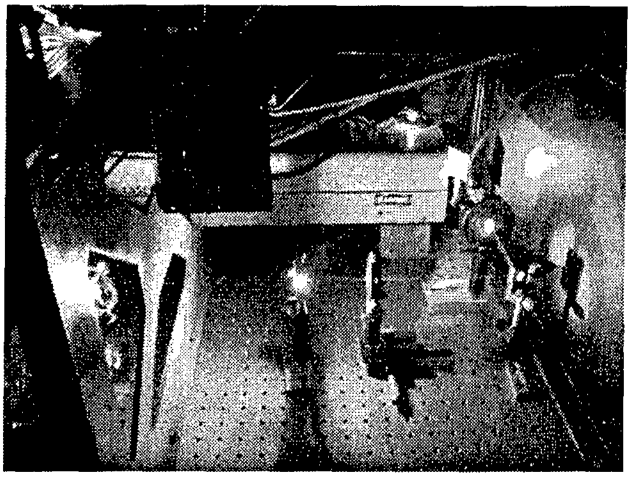

Fig. 5: Laser, shutter and beam expander assembly

RESULTS AND POSSIBLE APPLICATIONS

The laser micromachining system will permit the direct scaling of a wide variety of waveguide and optical structures to THz frequencies. One such device is a "Magic-T". Figure 6 is a conceptual design for a 0.85 THz mixer that coherently combines the signals from two independent telescopes using a Magic T before downconversion. The local oscillator is injected using a micromachined directional coupler. An array of such mixers is shown in Figure 6. We plan to propose to build such an instrument [3] for use on the Large Binocular Telescope now being constructed on Mount Graham, Arizona.

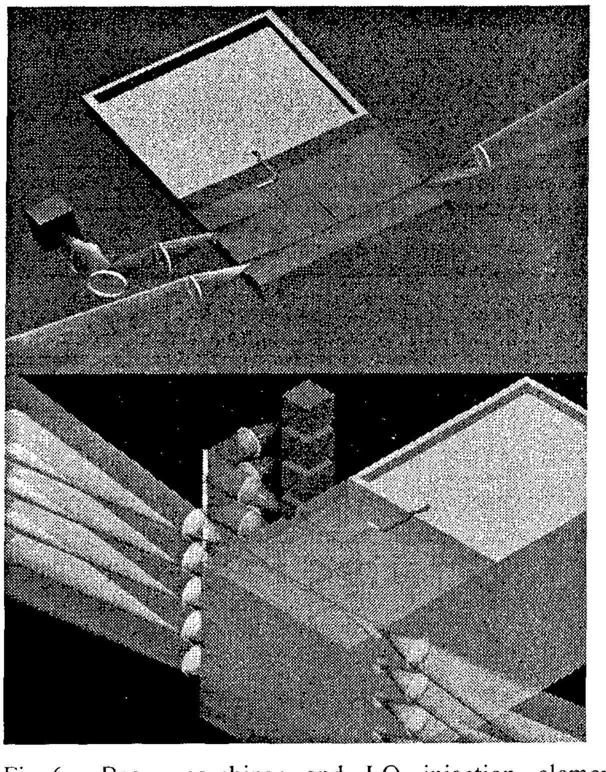

Fig. 6: Beam combiner and LO injection element design (top). Proposed beam combiner array for the LBT (bottom).

Figure 7 is a conceptual drawing of an integrated, micromachined, 2 THz array receiver being developed for SOFIA, the Stratospheric Observatory for Far Infrared Astronomy [3]. Test feedhorns for the array (Fig. 8) were fabricated using the parent laser micromachining system at Lincoln Laboratory and successfully tested at Steward Observatory [4].

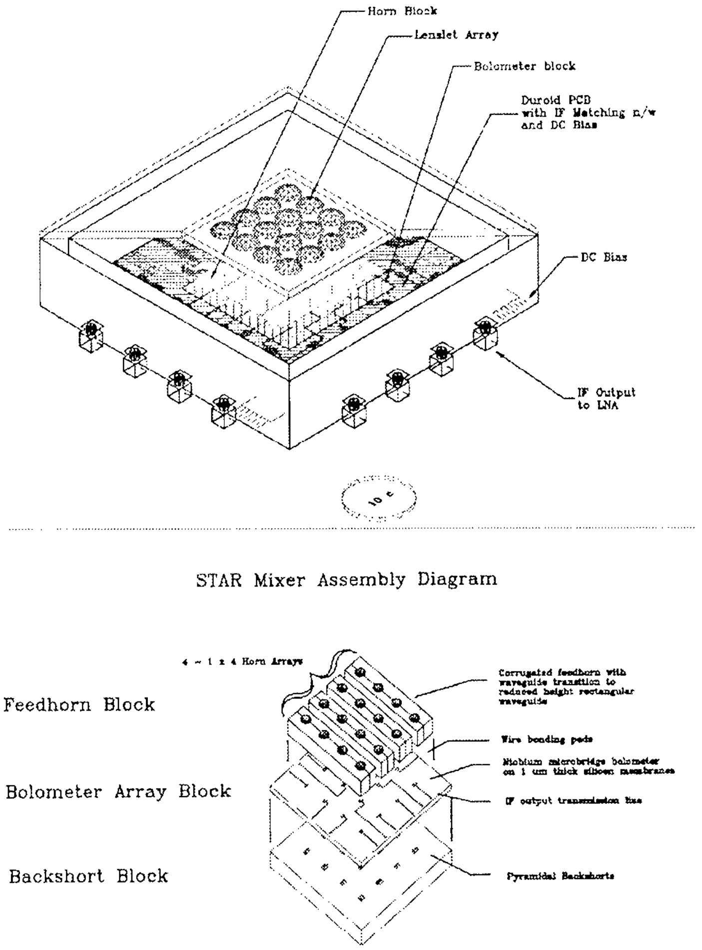

Fig. 7: SOFIA 2 THz, 4x4 array design

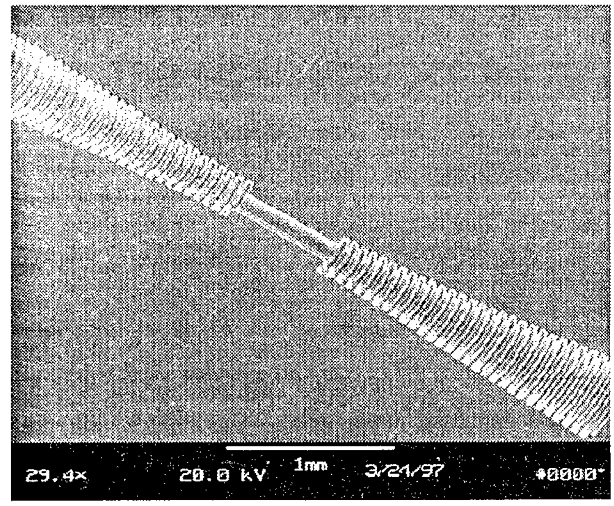

Fig. 8: Feedhorn produced at Lincoln Laboratories.

CONCLUSION

Laser etching not only makes the construction of THz waveguide arrays tractable but it is also ideally suited to make submillimeter phase gratings, high efficiency feedhorns to replace Winston cones in large bolometer arrays, AR grooving in silicon lenses and more. Optical diagrams, waveguide pictures and conceptual diagrams are available at:

http://soral.as.arizona.edu/micromachining.html

Acknowledgements

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